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Wind Effect on Fire Behavior in Compartment

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ABSTRACT

For the wind effect on the burning cribs in unconfined space and in compartment, it has not been well discussed in spite of its importance. Now we are performing the research project on Disaster Prevention in Town Planning and are planning the fire experiments. In this paper we introduce the state of the art of the experimental results of burning wood cribs in the compartment and in unconfined space using BRI Fire Research Wind Tunnel (BRI FRWT).

In this work it was shown that the mass loss rates of cribs in unconfined space and in compartment with or without ceiling are proportional to wind velocity. And the equivalence ratio ϕ varied in the wide range from around 2 (fuel rich) to around 0.5 (air rich).

1. INTRODUCTION

A lot of studies concerning compartment fire have been done. But the most of them deal with the fire phenomena without wind effect. Because the air plays a very important part in fire phenomena, the wind effect is very important. When the wind blows strongly and fire happens, after windows beak out, fire spreads rapidly and largely, in such cases it happens to become city fire.

The cellulosic materials are the main combustibles of actual fire, and wood crib is general to be used as the fuel in previous experimental work. There are a lot of models to describe mass loss rates of unconfined burning of crib without wind[1-4]. Because in these models the air entering in cribs is one of the parameters governing the mass loss rates of the burning cribs, it is expected that the air entering in cribs by wind will be the parameter, too.

For the wind effect on the burning cribs, Harmathy[5] indicates the effects of forced ventilation on the burning cribs by experiments using air chamber. Because he supplies air into cribs from 4 sides, the result is not clear to apply for the effect of natural wind blowing on the combustibles.

The main purpose of previous work of burning cribs in wind is to make a model of flame length[6,7]. But basically it has not been well discussed about the wind effect on the mass loss rates of the burning cribs, even though it is important for fire safety.

For the wind effect on the burning combustibles in compartment, Ogawa et.al.[8] examined experimentally using the Methanol as fuel. But it has not been discussed for the cellulosic materials.

Now we are performing the research project on Disaster Prevention in Town Planning and plan the fire experiments. In this paper we introduce the state of the art of the experimental results of burning wood cribs in the compartment and in unconfined space using BRI FRWT.

2. EXPERIMENT

2.1 Burning of cribs in unconfined space in wind

The crib1 ~ crib3 shown in Table 1 were used as the combustible. The two layers of ceramic board of 0.025m were put on the table of weighing device for insulation. The nominal wind velocity was 0, 2, 4, 6, 9 m/sec using BRI FRWT. The three or four sticks of insulation board of 0.01m*0.01m*0.45m soaked with Methanol were used as the igniter. The weight of crib was measured by load cells (Transducer C2M1-50k, MINEBEA Co., LTD) and the wind velocity was measured by the anemometer (Kanomax Anemomaster Model6141, NIHON KAGAKU KOGYO Co., LTD) at the position of 5m windward and 0.97m height at the interval of 0.5 second.

Table 1 The specification of crib

	n	*N*	*W0*	*h*	*Af*	*As*	*Ab*	*vin*
crib1	8	6	11.42	0.18	2.2704	0.0234	0.0676	0.586
crib2	6	8	11.42	0.24	2.4228	0.0384	0.1024	0.676
crib3	8	11	20.64	0.33	4.1664	0.0390	0.0676	0.793

The stick of 0.03m*0.03m*0.5m of Douglas fir was used for crib.
The percentage of water content was 7.7%

2.2 Burning of cribs in compartment in wind

The crib3 shown in Table 1 were used as the combustible. The enclosure of 0.6m*0.6m*0.6m (inside dimension) was employed as compartment and had the openings of 0.3m width and 0.25m height on the center of windward wall and leeward wall. The ceramic fiber board of 0.025m was used for the material of wall, ceiling and floor. The experimental condition was the difference of wind velocity and with or without ceiling. The nominal wind velocity was 2, 3, 4, 6, 9 m/sec using BRI FRWT and in case of 0 m/sec the experiments were done in the experimental room to measure heat release rate by oxygen consumption method. The weight of crib was measured by load cells (Transducer C2M1-50k, MINEBEA Co., LTD) installed under the table of which studs penetrating the floor of enclosure and the wind velocity was measured by the anemometer (Kanomax Anemomaster Model6141, NIHON KAGAKU KOGYO Co., LTD) at the position of 5m windward and 0.97m height at the interval of 0.5 second.

3. RESULTS AND DISCUSSION

3.1 Burning of cribs in unconfined space in wind

From the scaling laws[9] the requirement for the similarity between the model and the original phenomenon is shown as below. The ratio of buoyant force and inertial force, generally one of the pi-numbers, is shown in Eq.(1).

$$\pi_1 = \frac{\rho v^2}{\Delta\rho l g} \qquad (1)$$

For the similarity between the model and the original phenomenon, from Eq.(1), Eq.(2) is derived.

$$\frac{v}{v'} = \frac{t}{t'} = \left(\frac{l}{l'}\right)^{1/2} \qquad (2)$$

Here the prime indicates the model. Regarding the mass loss rate, Eq.(3) is derived.

$$\frac{m}{m'} = \frac{\rho g l^3 t'}{\rho' g' l'^3 t} \qquad (3)$$

Here from Eq. (2), Eq. (3) can be shown as formula (4).

$$\frac{m}{m'} \propto \left(\frac{l}{l'}\right)^{5/2} \qquad (4)$$

In previous work there are a lot of models to describe mass loss rate of unconfined burning of cribs without wind [1-4], but there is few models to satisfy the relationship of formula (4).

The experimental results of the mass loss rates of cribs in unconfined space in wind are shown in Fig.1 ~ 3. The mass loss rates of 3 kinds of cribs show linear correlation with wind velocity. And Fig.4 shows the relationship among 3 kinds of cribs by dividing the mass loss rate by the exposed surface area of cribs. From these results the next relationship of formula (5) and (6) can be derived.

$$\frac{m}{Af} \propto v \qquad (5)$$

$$\frac{m}{m'} \propto \frac{A_f\, v}{A_f'\, v'} \propto \left(\frac{l}{l'}\right)^{5/2} \qquad (6)$$

The result shows the agreement with formula (4) from the consideration of scaling laws for dimensional relationship. The validity of these relationship is shown by Emori and Saito [9]. Furthermore it may be that formula (5) and (6) need non-dimensional parameter including characteristic length.

Then assuming ΔT =800, $T0$ =300, the air velocity into crib without wind is defined by Eq. (7) and the value of the air velocity is shown in Table 1. And the value of v_{in} is shown in Fig.1 ~ 3 as the open symbol.

$$v_{in} = \left(\frac{1}{(n\text{-}1)(\mathrm{N}\text{-}1)}\right)\left(\frac{T_0}{T_0+\Delta T}\right)\sqrt{2gh\frac{\Delta T}{T_0}} \qquad (7)$$

From the experimental observation the air into crib enters from only one side of crib for more than 2 m/sec of nominal wind velocity.

The experimental results in compartment show that there is little influence of the thermal environment of enclosure on the mass loss rate, because the mass loss rates do not increase in enclosure and previous work [10] indicates. It is needed for further consideration and interpretation of the combustion phenomena of wood crib.

For ϕ assuming ϕ_s=0.2 [11], it varied in the wide range from 1.89 to 0.47 as shown in Table 2, but the mass loss rates can be shown in linear correlation.

3.2 Burning of cribs in compartment in wind

It is easy to expect that the mass loss rate in compartment will increase with wind velocity, because basically the mass loss rate of crib increases with wind velocity. But the parameter governing the mass loss rate is the velocity, not the amount of air, the velocity in

Table 2 The estimated value of ϕ

nominal wind velocity	crib1	crib2	crib3
0 m/s	1.62	1.23	1.89
2 m/s	1.59	1.18	1.77
4 m/s	0.95	0.71	1.10
6 m/s	0.78	0.51	0.85
9 m/s	0.61	0.47	0.67

compartment is not so simple.

The experimental results are shown in Fig.5 and Fig.6. With or without ceiling, the mass loss rates seem to be linear to wind velocity. However in case with ceiling the inclination of the graph is smaller than that in unconfined space in wind, in case without ceiling the results were almost as same as that in unconfined space. The amount of air entering through the opening is estimated as Eq.(8).

$$m_a = \alpha A v\rho \sqrt{C_u - C_d} \sqrt{\frac{T_0}{2T_0 + \Delta T}} + 0.526 A \sqrt{H} \qquad (8)$$

For ϕ assuming ϕ_s=0.2 [11], it varied in the wide range from 1.65 to 0.58 as shown in Table 3.

Table 3 The estimated value of ϕ in compartment

nominal wind velocity	0m/s	2m/s	3m/s	4m/s	6m/s	9m/s
with ceiling	1.65	1.02	0.95	0.81	0.64	0.58

4. CONCLUSION AND FURTHER WORK

From this work we could derive the following.

- The mass loss rates of cribs in unconfined space and in compartment with or without ceiling are proportional to wind velocity.
- ϕ varied in the wide range from around 2 (fuel rich) to around 0.5 (air rich).

It is needed for us to further experimental consideration and interpretation about the following.

- Burning of cribs in unconfined space in wind
  :size and length of sticks of crib
- Burning of cribs in compartment in wind
  :size and number of the opening
  :direction of wind to the opening

5. ACKNOWLEDGEMENTS

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NOMENCLATURE

A : area of opening of enclosure (m^2)
Ab : total area of opening of bottom of cribs (m^2)
Af : exposed surface area of cribs (m^2)
As : total area of opening of one side of cribs (m^2)
b : stick size (m)
Cu : wind pressure coefficient (windward) (-)
Cd :wind pressure coefficient (leeward) (-)
g : gravitational acceleration (m/s^2)
h : height of crib (m)
l : characteristic length (m)
L : length of stick in crib (m)
m : mass loss rate (kg/sec)
ma : mass of air (kg/sec)
n : number of sticks per layer in crib (-)
N : number of layers on crib (-)
s : spacing between sticks in crib (m)
t : time (sec)
T : absolute temperature (K)
$T0$: ambient temperature (K)
ΔT : excess temperature of gas of the vertical shaft of the crib at the height of crib (K)
U : wind velocity (m/s)
v : velocity (m/s)
vin : the air velocity into crib (m/s)
$W0$: initial mass of crib (kg)
α : flow coefficient (-)
ρ : density (kg/m^3)
ϕ : equivalence ratio (-)
ϕ_s : stoichiometric reacting fuel to air ratio (-)

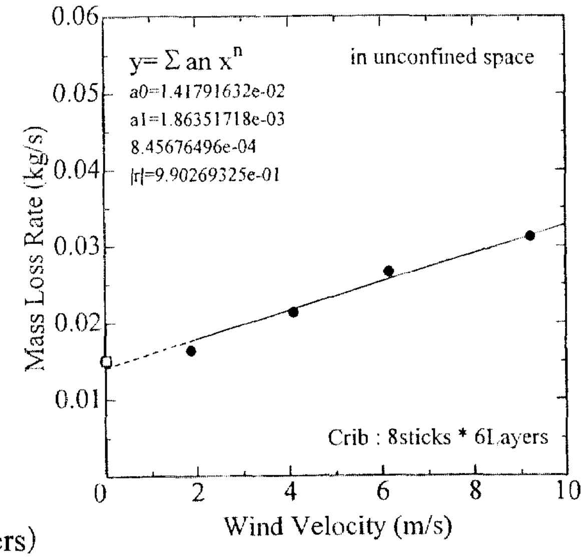

Fig.1 Relationship between Wind velocity and Mass loss rate (Crib1 : 8sticks * 6layers)

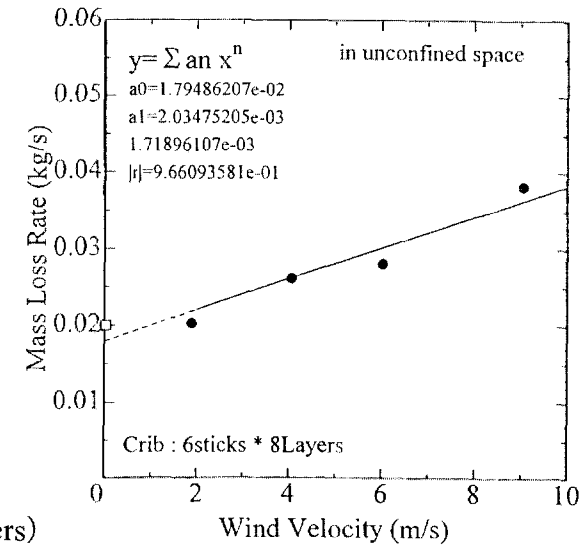

Fig.2 Relationship between Wind velocity and Mass loss rate (Crib2 : 6sticks * 8layers)

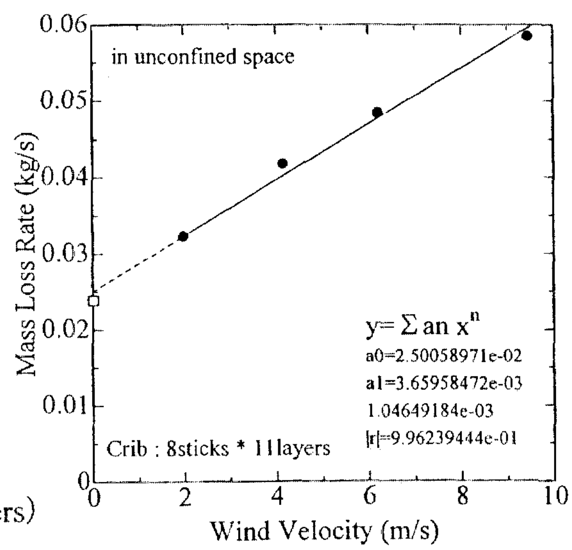

Fig.3 Relationship between Wind velocity and Mass loss rate (Crib3 : 8sticks * 11layers)

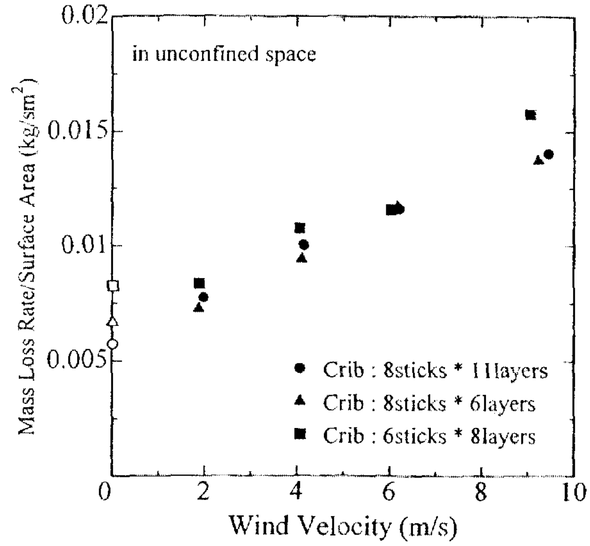

Fig.4 Relationship between Wind velocity and Mass loss rate

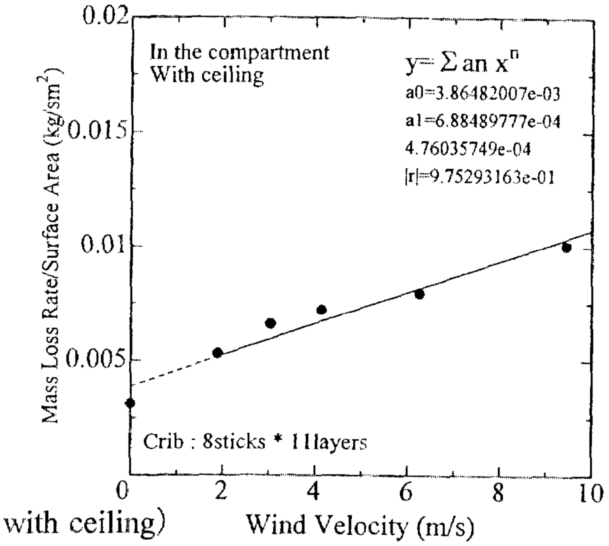

Fig.5 Relationship between Wind velocity and Mass loss rate (in the compartment with ceiling)

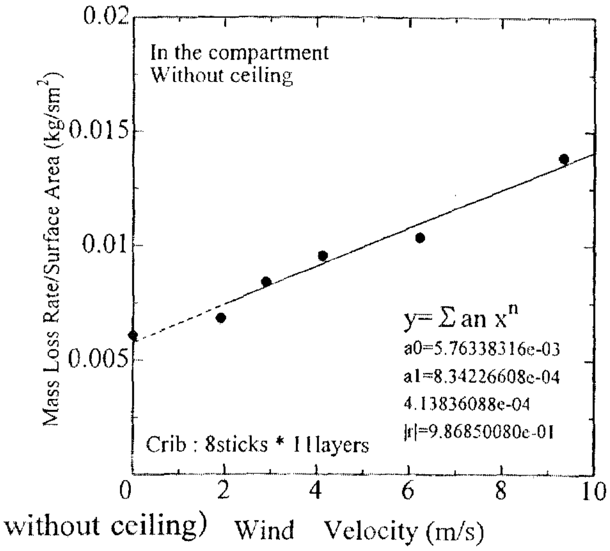

Fig.6 Relationship between Wind velocity and Mass loss rate (in the compartment without ceiling)